Research Proposal Submitted to

U.S. DEPARTMENT OF ENERGY

by

University of Hawaii
Honolulu, Hawaii 96822

PHASE IV

KAPOHO GEOTHERMAL RESERVOIR ASSESSMENT

Hawaii Geothermal Project

Amount Requested: $100,000

Proposed Duration: Six Months

Requested Starting Date: April 1, 1978

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Hawaii Geothermal Project - Phase IV

KAPOHO GEOTHERMAL RESERVOIR ASSESSMENT

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I. INTRODUCTION

This is a proposal to the U.S. Department of Energy for continued support of the Hawaii Geothermal Project. Funding for six months from April 1, 1978 through September 30, 1978 is requested for Phase IV, which will continue the work started in Phase III and also obtain data necessary to define HGP-A and the Kapoho geothermal reservoir. A budget of $100,000 is required for the proposed research. Descriptions of the various parts of the Project are given below.

A. Summary of Previous Work

1. <u>Site Selection and Drilling</u>

The Hawaii Geothermal Project was organized in 1972 to locate and utilize geothermal energy resources in Hawaii. Research got underway in the early summer of 1973 with separate programs established for Geophysics, Engineering, and Environmental-Socioeconomics. Later an Experimental Drilling program was added. The major emphasis of the initial phase was on a geophysical program which was designed to select a geothermal well site and develop an understanding of the thermal processes of a basaltic volcano and its associated rift zones. Various geophysical surveys were utilized: infra-red, surface manifestations, gravity, magnetic, electrical, well temperature, seismic, geochemical and hydrological. Data from a self-potential survey by the U.S. Geological Survey were also used.

The Site Selection Committee was chaired by the former Dr. Agatin T. Abbott, after whom the well was ultimately named -- HGP-A, with the "A" for Abbott. The committee considered all geophysical, geological, and geochemical evidence and selected as the optimum site a location on the Big Island in the Puna District near the eastern rift of Kilauea Volcano. No State or County land suitable for drilling was available near the selected site, and after negotiations with landowners in that area, permission was obtained from the Kapoho Land and Development Company to drill the well on a four-acre plot approximately three miles southeast of Pahoa. Figure 1 contains a map of the Big Island and the locations of HGP-A and the volcanoes and rift zones. The elevation of this site is about 600 feet above sea level.

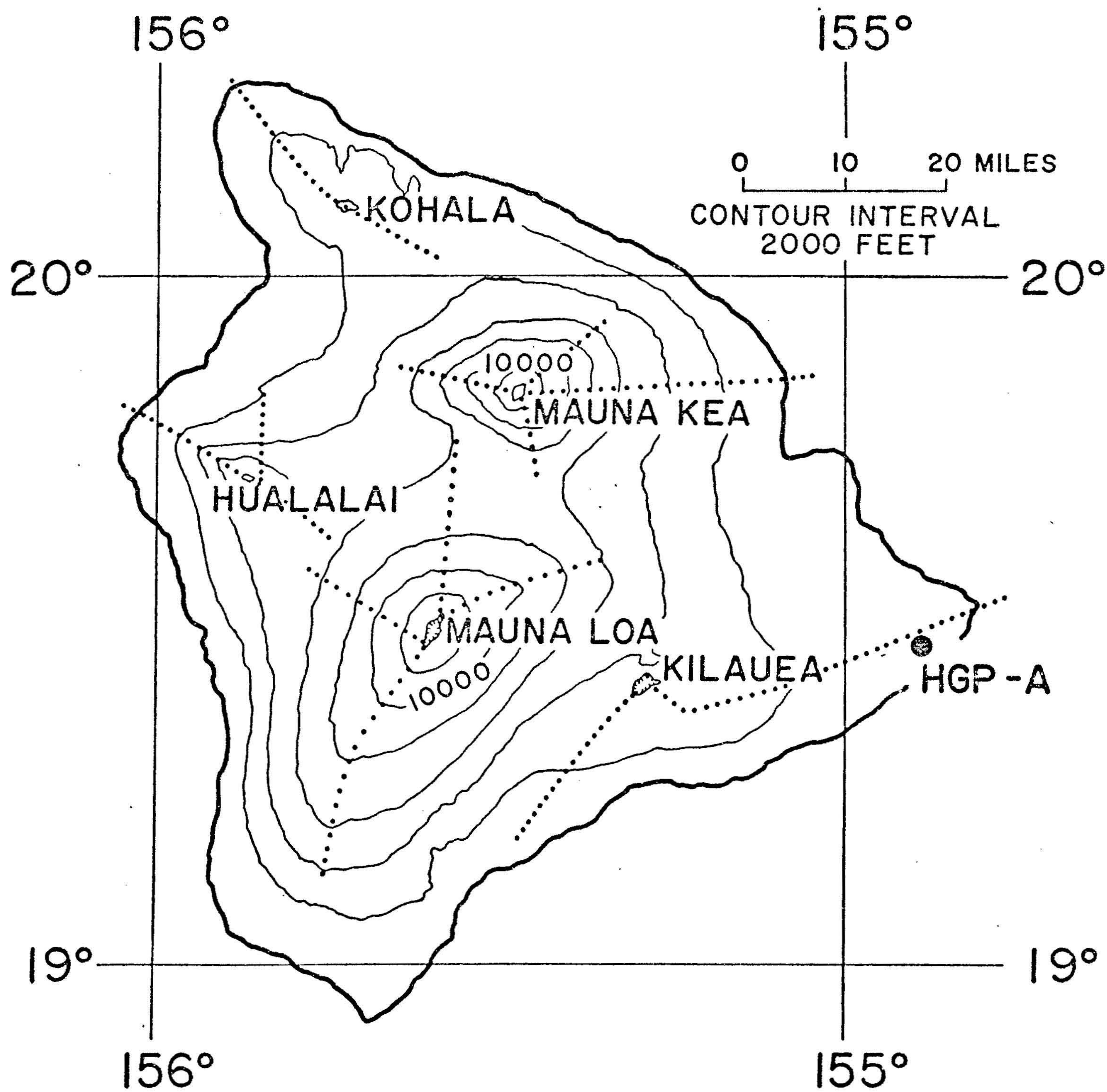


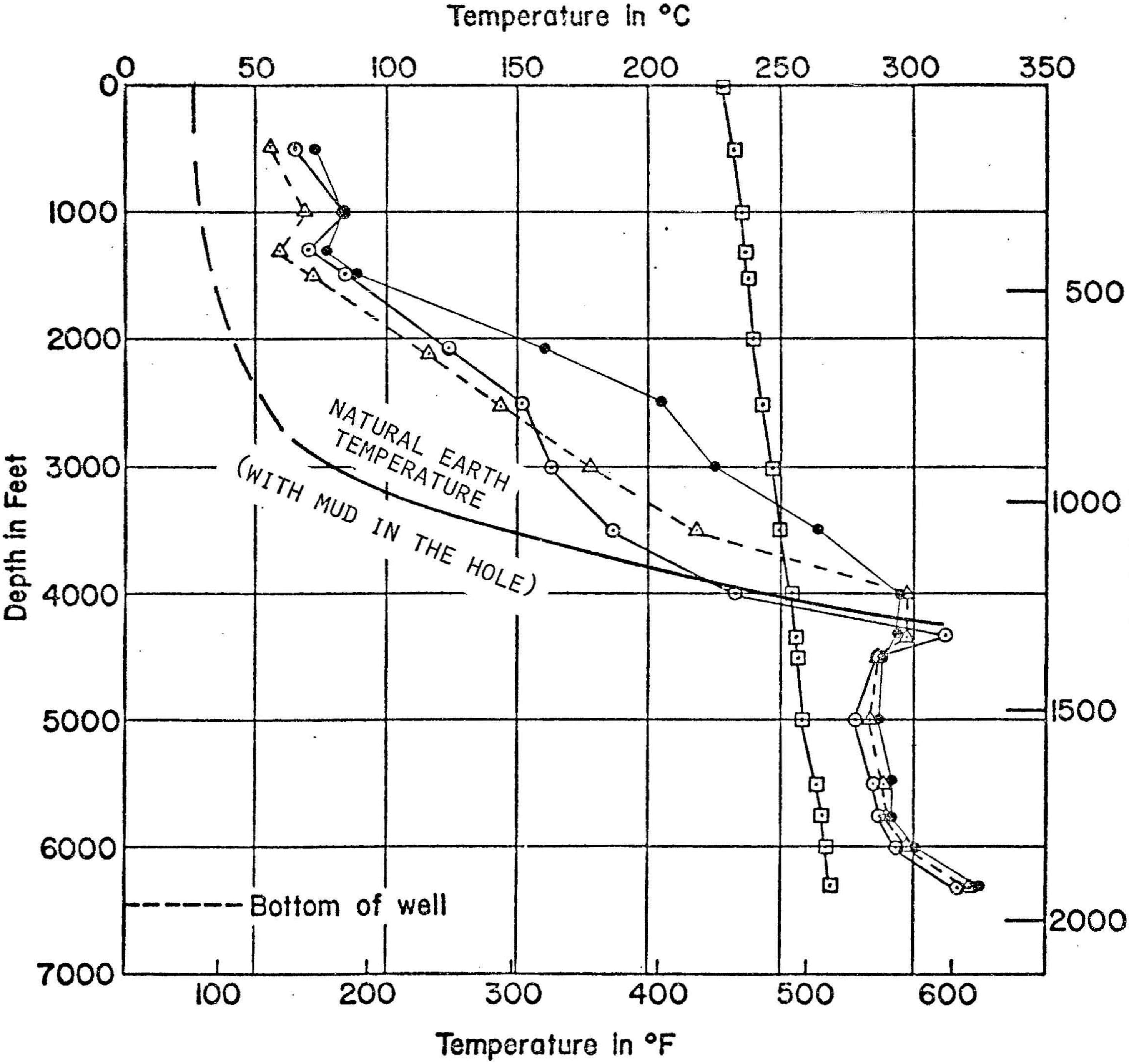
Figure 1. Locations of HGP-A, Volcanoes and Rift Zones

Water Resources International, Inc. of Honolulu was selected as the drilling contractor, and a New Zealand geothermal consulting firm, KRTA, was commissioned to provide technical assistance and supervision of the drilling operation. Drilling of this experimental well commenced on December 10, 1975. The well was completed to a depth of 6450 feet on April 27, 1976. Cores of the subsurface strata were taken at approximately 700-foot intervals and samples of cuttings were obtained for every five to ten feet of drilling. The well was logged twice with Gearhart-Owen equipment, which measured resistivity, self-potential, natural gamma ray and slow neutron count, and cement bond. Depth of logging was limited by surprisingly high downhole temperatures. In all subsequent measurements Kuster downhole instrumentation was used.

2. Well Testing Program

HGP-A was first flashed to steam and permitted to flow briefly on July 2, 1976. The rate of discharge of steam was impressive but noisy -- resulting in dBA readings of 120, roughly equivalent to that of a 747 jet aircraft at take off. Steam was discharged continuously for four hours on July 22, verifying that natural fluid flow into the wellbore was taking place. The quality of the fluid from HGP-A was generally good -- surprisingly low in chloride content, but with expectedly high amounts of silica. A bottomhole temperature of 676°F (358°C) has been measured, making HGP-A the hottest geothermal well in the nation.

In order to proceed with a testing program a silencer/separator was installed to muffle the noise and separate the steam from the water. Temperature and pressure profiles throughout the full 6450-foot well depth have been obtained. Figure 2 contains typical temperature profiles during quiescent and discharge periods. It is of especial interest that each succeeding test has improved well performance. Table 1 indicates this improvement. In late December and early January muffling and stiffening were added to the silencer, after which a series of throttled flow tests was conducted to provide a better assessment of the well and to obtain preliminary design data for a wellhead generator. Table 2 summarizes the test results. The probable operating conditions for a turbine generator are those obtained with a 3" orifice. Steam under 165 psi of pressure at 60% steam quality flows to the surface, where the steam is separated and used to generate electricity. Higher pressures, if necessary, can be obtained by throttling the flow further. Figure 3 is a sketch of the present wellhead and silencer assemblies.



⊡——⊡	2/10/77	Well Discharging with 1 3/4" Orifice Plate
⊙——⊙	2/19/77	8 Days after Shut-in
△- - -△	2/25/77	14 Days after Shut-in
●——●	3/8/77	25 Days after Shut-in

Figure 2. Temperature Recovery After January Flow Test

Table 1

COMPARISON OF DISCHARGE TESTS AT 25 HOURS AFTER INITIATION OF FLOW

	NOVEMBER	DECEMBER	JANUARY	MARCH
WELLHEAD PRESSURE (PSIG)	47	53	59	59
WELLHEAD TEMPERATURE (°C)	146	150	151	153
LIP PRESSURE (PSIG)	7.9	10.1	12.5	13.9
WEIR HEIGHT (INCHES)	3-1/2	4	4-1/8	4-3/16
WEIR TEMPERATURE (°F)	203	205	205	203
MASS FLOW RATE (KLB/HR)	87.9	103.4	114.3	120.4
LIQUID FLOW RATE (KLB/HR)	27.9	39.5	42.5	45.2
STEAM FLOW RATE (KLB/HR)	60.0	63.9	71.8	75.2
STEAM QUALITY (%)	68	62	63	62
ENTHALPY (BTU/LB)	888	833	845	842
THERMAL POWER (MW)	22.9	25.2	28.3	29.7
ELECTRICAL POWER (MW)	3.4	3.8	4.3	4.5

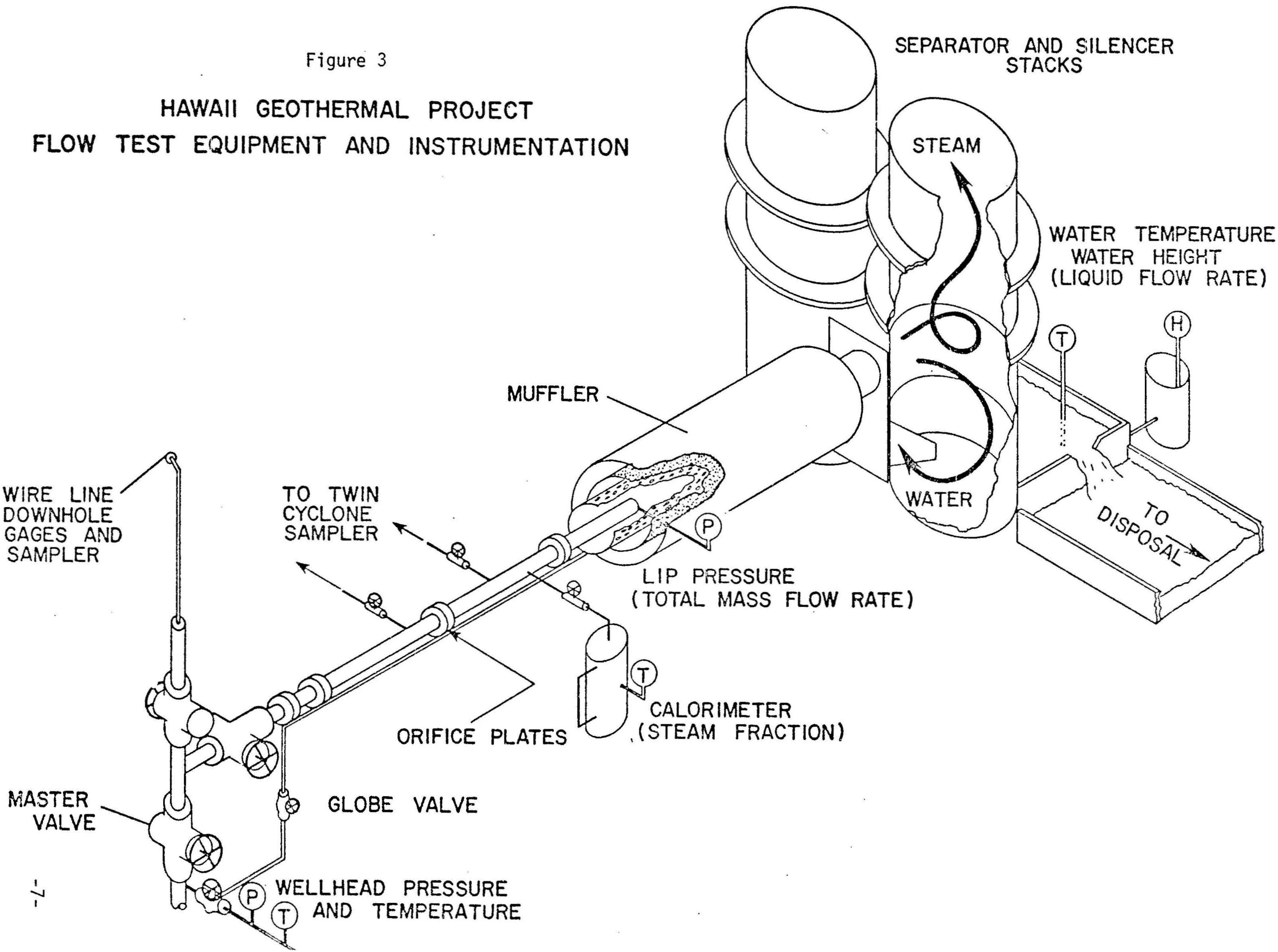
Table 2

THROTTLED FLOW DATA

ORIFICE SIZE (INCHES)	TOTAL MASS FLOW RATE (KLB/HR)	STEAM FLOW RATE (KLB/HR)	STEAM QUALITY (%)	WELLHEAD PRESSURE (PSIG)	WELLHEAD TEMP. (°F)	POSSIBLE ELECTRICAL POWER OUTPUT (MWE)
8	101	64	64	51	295	3.3
6	99	65	66	54	300	3.4
4	93	57	64	100	338	3.5
3	89	54	60	165	372	3.5
2-1/2	84	48	57	237	401	3.3
2	81	43	53	293	419	3.1
1-3/4	76	39	52	375	439	3.0

Figure 3

HAWAII GEOTHERMAL PROJECT
FLOW TEST EQUIPMENT AND INSTRUMENTATION



The results of these preliminary tests were sufficiently encouraging that a ninety-day flow test was begun in late March, 1977. However, the nuisance effects of both the noise and the hydrogen sulfide emissions combined with the fact that the pressure-time curves for the well seemed to stabilize early led to the termination of the test after six weeks on May 9.

It should be noted that once a wellhead turbo-generating system is installed with the proper H_2S scrubbers, noise and odor problems will disappear. The early installation of a wellhead generator, both to provide power for the Big Island electric grid and to obtain additional information on the nature and the extent of the geothermal resource, is the next logical step for developing the Kapoho geothermal reservoir. Negotiations are now in progress with the U.S. Department of Energy for such a wellhead generator.

Table 3 contains a timetable of important well testing events.

3. Summary of Analyses

A megascopic study of the well cuttings and a microscopic/X-ray diffraction study, primarily of core samples, provided information from which possible production regions could be deduced. In general, permeabilities appear high from the surface down to about 3000 feet, with a very high permeability layer just below the bottom of the casing, at around 2500 feet, down to 3300 feet. Permeability is low from 3300 feet to very close to the bottom. However, it is possible that secondary production zones of medium permeability could exist in this interval. The permeability near bottomhole appears to be quite high. Figure 4 contains a sketch of a possible model of the underground system.

Standard petroleum engineering techniques, which assume single phase flow, were used to analyze the production flow test data. These indicate that the permeability-thickness is approximately 1000 millidarcy-feet; skin damage appears to be present. Production from more than one layer is suggested when data are plotted on a Horner plot. Examination of temperature and pressure profiles taken while the well was flashing indicates that the flow is a saturated mixture of vapor and liquid. Also, as there is no detectable liquid level in the wellbore during flow, flashing must be occurring in the reservoir.

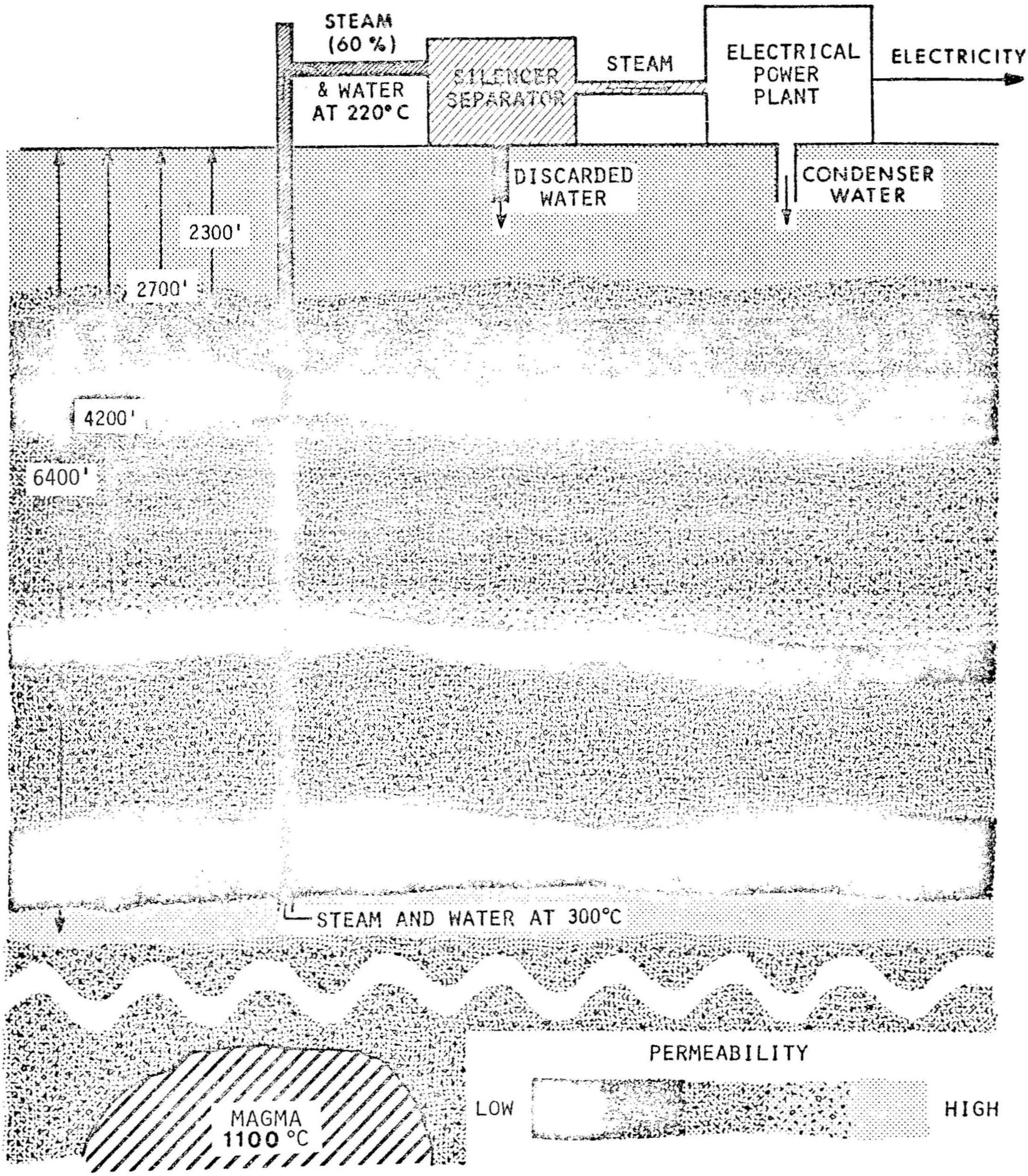
The production fluid is slightly saline (about 5% ocean water) and nearly deplete of magnesium but contains relatively high concentrations of silica and sulfide. The water is contrastingly low in tritium content compared

Table 3. Timetable of Well Testing Events

	1976									1977							
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
WELL STATUS																	
Airlifting			•	•					•								
Preliminary Flow and Tests			•	•			•	•	•			•					
Throttled Flow Test									•	•	•						
Production Flow Tests				•				•	•			•	•	•			
ACTIVITY																	
Pressure Drawdown Measurements								•									
Pressure Buildup Measurements									•	•	•	•		•			
Temperature Profile Measurements	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•
Pressure Profile Measurements			•	•	•	•		•	•	•	•	•	•	•			•
Water Level Measurements								•	•	•	•	•		•	•	•	•
Downhole Water Sampling					•		•	•	•	•	•		•	•			

Figure 4

POSSIBLE MODEL OF HGP-A UNDERGROUND SYSTEM



with the surrounding groundwater as close as 1 mile away, thus suggesting the existence of possible geologic boundaries. The pH value downhole is low (2 to 3), but as CO_2 comes out of solution, the pH at wellhead rises to neutrality.

The fluid is remarkably free of toxic elements. The mercury emission into the air during discharge is insignificant relative to normal ambient conditions. However, the hydrogen sulfide concentration, while low, is a nuisance to residents in the surrounding areas.

These results are summarized in Table 4, which contains information on the well and the reservoir; Table 5, which contains a summary of the gas analyses; and Table 6, which contains a geochemical summary of the well effluents.

Table 4

Summary of Preliminary Test Results and Analyses

Kapoho Geothermal Reservoir

1. Liquid-dominated
2. Tight Formation: Permeability Thickness $\sim$1000 md-ft
3. Very High Temperatures $\sim$350°C
4. High Formation Pressure $\sim$2000 psi
5. Slightly Brackish Water
6. Potentially Large Reservoir
7. High Silica Content

HGP-A Geothermal Well

1. During Flash Borehole Contains Steam and Water at Saturation
2. Flashing Occurs in Formation
3. High Wellhead Pressures $\sim$160 psi at 60 klb/hr Steam
4. Producing Regions Probably at Bottomhole and 4300 feet
5. Probably Has Severe Skin Damage
6. Potential Power Output $\sim$3.5 MWe
7. Flows Have Increased With Each Test

TABLE 5

SUMMARY OF GAS ANALYSES FOR HGP-A

Date/Type of Sample	Sampling Pressure (psi)	Temp. (°C)	Total Gas Content (mg/kg of discharge)	Composition (wt %) CO_2	H_2S	N_2	H_2	Mole Ratio CO_2/H_2S	N_2/H_2
29 Jan. 1977; Total Condensate from Cooled Cyclone Separator	50	30	991*	72	10	18	0.1	5.5	19.5
5 April 1977; Steam from Cyclone Separator	165	185	1604	59	20	21	0.5	2.3	3.0
9 May 1977; Steam from Cyclone Separator	167	188	1912	57	21	21	1	2.1	2.4
	40	188	2697	65	24	10	.4	2.1	1.8
19 July 1977; Steam from Cyclone Separator	25	180	1337	71	18	11	.5	3.0	1.6
Best estimate for total gas content of HGP-A	-	180	2100	60.3	21.7	17.3	.6	2.1	2.1

*The 29 Jan. 1977 values most closely reflect the composition of the HGP-A stack emissions.

TABLE 6

HGP-A GEOCHEMICAL SUMMARY
(concentrations in mg/l of total discharge)

	Cl	Na	K	Ca	Mg	SiO_2	$S^{=}$	pH	Conductivity (μmhos/cm)	Salinity (%)	Tritium
DOWNHOLE											
Quiescent (average of 5 profiles):											
mean	1040	730	122	91.2	1.0	440	135	<5	3100	2.3	<.1
σ	±465	±272	±46	±63	±.7	±230	±96				
Discharge	3600	1300	225	80	-	135	-	8.5	5900	4.6	-
WEIR BOX											
Approximate steady-state (01/30/77)	780	390	68	24	.11	41	-	8.5	-	-	-

II. PROPOSED PROGRAM

A. Summary

As a result of the tests and analyses described previously, some information is available concerning the Kapoho geothermal reservoir. However, considerably more data are required about the characteristics of the reservoir, e.g., volume, energy content, deliverability, if an assessment of the economic viability of the region is to be made. Additional geophysical, geochemical, hydrological, and engineering studies need to be conducted to define the boundaries of the resource.

This proposal addresses these needs and the work described will be a start towards producing data and models relevant to HGP-A and to the Kapoho geothermal field. The efforts of the Hawaii Geothermal Project in Phase IV will be concerned with analyses of these data and models, and their integration into working hypotheses which will better define the parameters of the Kapoho geothermal field and will provide a better understanding of the extent and characteristics of that geothermal reservoir.

Following these analyses, an attempt will be initiated to synthesize a working description of the Kapoho geothermal field, so that information can be extracted concerning the parameters of the field and the operation of HGP-A and other wells. The specific questions that need to be answered are:

1. What are the geological/geophysical characteristics of the Kapoho geothermal field?
   a. Areal extent
   b. Depths and thicknesses of permeable layers providing fluids to the well
   c. Total available energy
   d. Nature and location of heat source
   e. Relationship to other geothermal fields in Puna
2. What are the hydrologic characteristics of the reservoir?
   a. Composition and age of fluid
   b. Fraction of total well output being provided by each type of source: ocean water, meteoric water, hydrothermal fluid
   c. Extent of fresh water sources being tapped by the well as determined by tritium and ^{14}C age dating

   d. If there is recharge, where is it occurring and at what rate
   e. Reason for apparent lack of communication with the ocean
3. What characterizes Hawaiian geothermal fluids?
   a. Sources and concentrations of geochemical thermometers (Na^+, K^+, Ca^{++}, SiO_2, etc.) in the hydrothermal component of the well fluids
   b. Sources and concentrations of magmatic gases (CO_2, H_2S, ^3He, etc.) in the well fluids
4. Are the typical isotopic geothermometers ($\delta^{18}O$, δD, and $\delta^{34}S$) reliable indications of thermal sources in Hawaii?
5. What will be the response of the reservoir to fluid withdrawal?
   a. Number and location of production wells
   b. Production life
6. What will be the impact on the surface environment of fluid withdrawal from the reservoir?
7. What will be the impact of long-term surface disposal of the well effluent?

Since support for only a six-month effort is being requested, longer-term work is being left for the next part of the Project. In particular, tests with one or more step-out wells are being postponed. However, now that the Hawaii Geothermal Rules and Regulations were finally approved on March 10, 1978 by the Department of Land and Natural Resources, efforts will be continued to obtain separate funding for the first step-out well to HGP-A. Also, in the six-month effort, only a start can be made towards answering these vital questions regarding Hawaiian geothermal reservoirs.

The following sections of the proposal describe the specific research to be carried out in Phase IV of the Hawaii Geothermal Project.

B. Geochemical Studies

Up to the present time the water chemistry analysis program for HGP-A has consisted of a series of 5 downhole water samplings at various depths under no-discharge conditions, one similar sampling under very low discharge conditions, and water quality monitoring of the well waters during discharge. The median values for the downhole water samples are given in Table 6. The chemical parameters measured under no-discharge conditions were not found to vary significantly with depth.

As shown in Table 6, the chemistry for discharge conditions is considerably different from that for shut-in conditions. Moreover, the water chemistry of the well fluids was found to vary substantially with time during each discharge with a slight increase in "steady state" ion concentrations with each succeeding discharge. Steady state ion concentrations were generally approached after two to three days of continuous discharge.

The results of water chemistry analysis made on a set of samples taken immediately following shut-in of the well after a fourteen-day discharge, has been found to indicate multiple sources of well fluids. The topmost sample, taken at a depth of 2270 feet was found to have anomalously high ion concentrations (Na^+, K^+, Ca^{++}, Cl^-) when compared with deeper samples taken on the same day and when compared with concentrations determined for earlier depth profiles.

The present interpretation of the above data is that there are at least two, and possibly more, sources of fluids in the well. It is thought that ocean water may be entering the well at shallow depth during discharge while during shut-in less saline water is entering the well, possibly at a different depth.

$^3He/^4He$ data obtained for HGP-A indicate that a significant portion of the well gases are of magmatic origin. This in turn leads to the conclusion that some of the water entering the well is magmatic or hydrothermally altered meteoric water. The depth of entry of this component into the well is uncertain at present but is thought to be in a region somewhat above the bottom of the well. Mass balance calculations based on present $\delta^{13}C$, ^{14}C, $\delta^{18}O$ and water chemistry data have tentatively assigned the well fluid contributions as follows: ocean water 10%, unaltered meteoric water 66%, and hydrothermal fluids 24%.

The proposed plan of research to answer the questions listed earlier follows. Several sets of downhole samples will be taken under a variety of conditions; each set will consist of samples of fluid taken at 500-foot intervals beginning at 2270 feet (the top of the slotted casing) and extending to the bottom of the well at 6300 feet. Water quality analyses will be made for the following: pH, Cl^-, $S^=$, $CO_3^=$, Na^+, K^+, Ca^{++}, Mg^{++}, and SiO_2. Analyses will also be made on selected samples for the following: $\delta^{18}O$, δD, $\delta^{13}C$ on dissolved carbonate, $\delta^{34}S$ on dissolved sulfide, radon and $^3He/^4He$.

Each set of samples will be taken under differing conditions in the well bore. The first set of samples will be taken under static conditions: the well will not have been discharged or disturbed for several days prior to sampling. The second set of samples will be taken after several days of warming (non-flashing) flow. Ideally, the well discharge will be monitored for salinity or chloride concentration and samples will be taken only after a relatively steady state concentration has been approached. This will be done to insure that there will be a relatively insignificant change in the well conditions over the period required for a complete set of samples.

The next set of samples will be taken after a moderate period of flashing. The well will be discharged for eight hours and then shut-in during the time required for sampling.

Samples will also be taken after a more extensive period of discharge lasting several days and a final set will be taken during the recovery period of the well following an extended discharge and subsequent quenching of the well.

The above sampling sequence will allow us to observe the chemical and isotopic profile of the well under a variety of conditions beginning with static (no discharge) conditions and extending to progressively greater draw off from the multiple sources of the well fluids. It is felt that this procedure will allow us to identify and characterize the various sources of water and gas in the well.

C. Geophysical Studies

1. Introduction

Evaluation of the economic potential of the Kapoho geothermal reservoir depends critically on the determination of the reservoir's dimensions. This determination can be attempted by geophysical means or by drilling. Since drilling costs in Hawaii average about $200 per foot, it is essential that we attempt to determine the areal extent of the reservoir by geophysical means rather than by drilling a large number of holes.

The depth of the top of the reservoir at the well site has been estimated to be at 3500 feet to 4000 feet (see Fig. 2) as a result of thermal measurements made in the well before the drilling mud was removed. Samples collected from the cores indicate an increase in pyrite in the reservoir region and a considerable amount of hydrothermal alteration, fracturing, and recementation. In view of these observations on material recovered from the well, and the thermal gradients for the well site, we can make some statements about the geophysical results that might be expected if the geology in the well is characteristic of the reservoir. These are:

a. No marked density contrast is associated with the reservoir. Therefore, gravity anomalies and seismic velocity will not be indicative of its boundaries.

b. Magnetic mineralogy changes within the reservoir; i.e., pyrite is present in place of magnetite; thus the reservoir may be modeled by a magnetic "hole" in normally magnetized basalt.

c. Salinity of reservoir fluids is low (approximately 10% that of sea water) and porosity is low; therefore, resistivity contrasts may not be large due to low fluid volume and salinity in the reservoir area.

d. The geochemistry of the hydrothermal fluid is acidic and reducing (low pH and H_2S is present); therefore, chemical potentials should be developed at its boundaries due to oxidation of the H_2S.

e. Large thermal contrasts are present at the upper boundary of the reservoir (250°C in 1000 feet); thus, thermal strains may be large and fracturing should be expected.

f. The He_3/He_4 ratio of the geothermal fluid (enriched 10 times over atmospheric ratio) is indicative of magmatic sources but due to sampling problems may not be a practical means of defining reservoir volume.

From these considerations, only two geophysical methods appear suitable for identifying the reservoir volume: magnetics and seismic (microearthquake and noise coherence).

The magnetic field has been measured in considerable detail at the surface during earlier portions of the HGP research. Surficial anomalies (dikes, variation in density, and variations in magnetic mineral abundance) seem to dominate the surface signal although a number of regional highs and lows can be identified. Due to the inherent ambiguity of potential methods relative to depth vs. volume and the large amplitude the signals from near-surface sources, we believe additional magnetic work at this time would not help define the boundaries of the reservoir.

From our past work the most promising geophysical techniques, in this particular region, are microearthquake distribution and seismic noise coherence. In our earlier exploration program we identified a number of microearthquakes in the immediate vicinity of the reservoir and at the depth of the reservoir as determined from drilling (see Figs. 5 and 6). The 39 events observed during this exploration effort are not sufficient to constrain adequately the areal

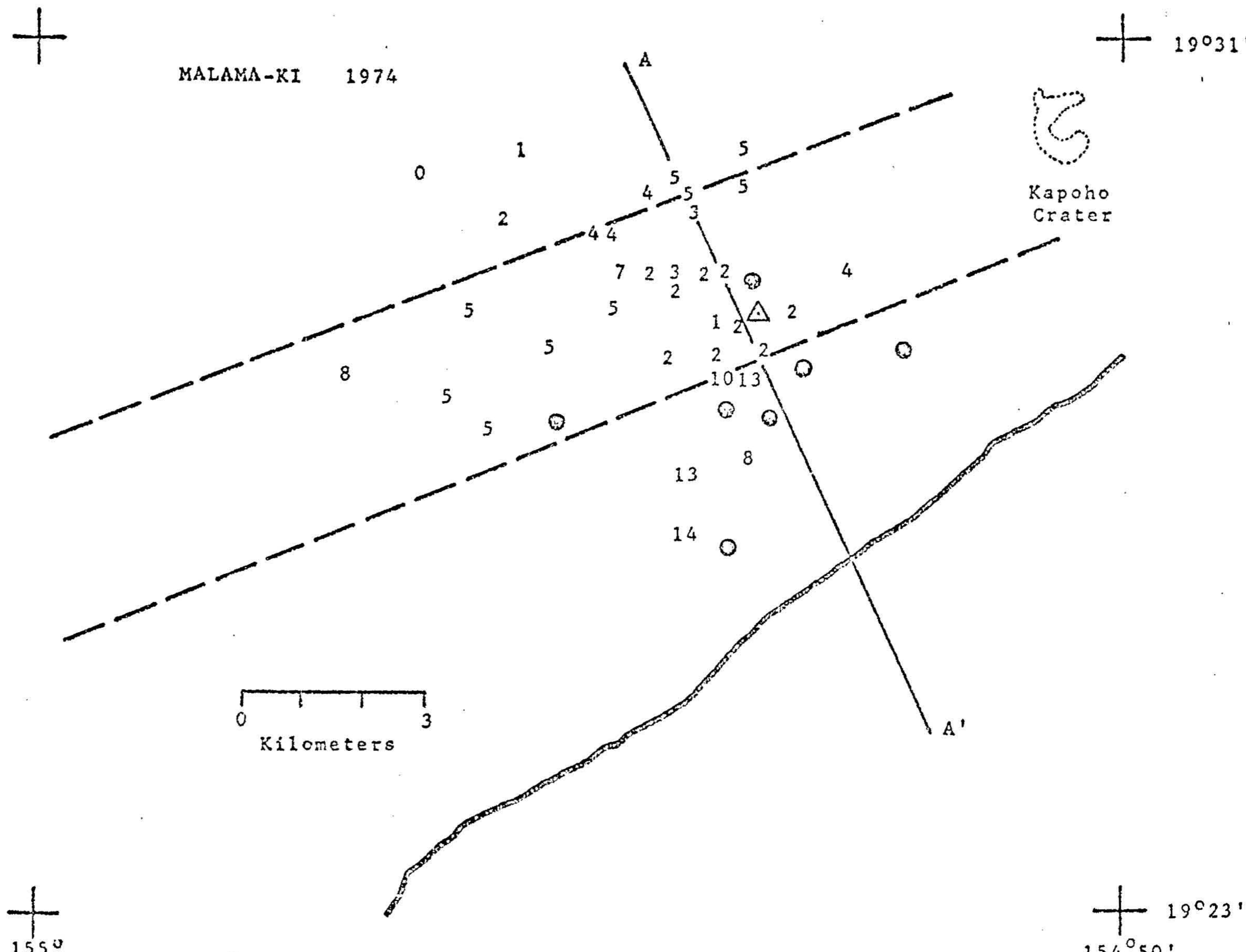


Figure 5. Epicenters of microearthquakes located by the Malama-Ki array, August-September, 1974. Dots are seismometer locations. Numbers on epicenters indicate depth in kilometers. Dashed lines indicate approximate boundary of the surface expression of the rift zone. Triangle shows site of the HGP-A well.

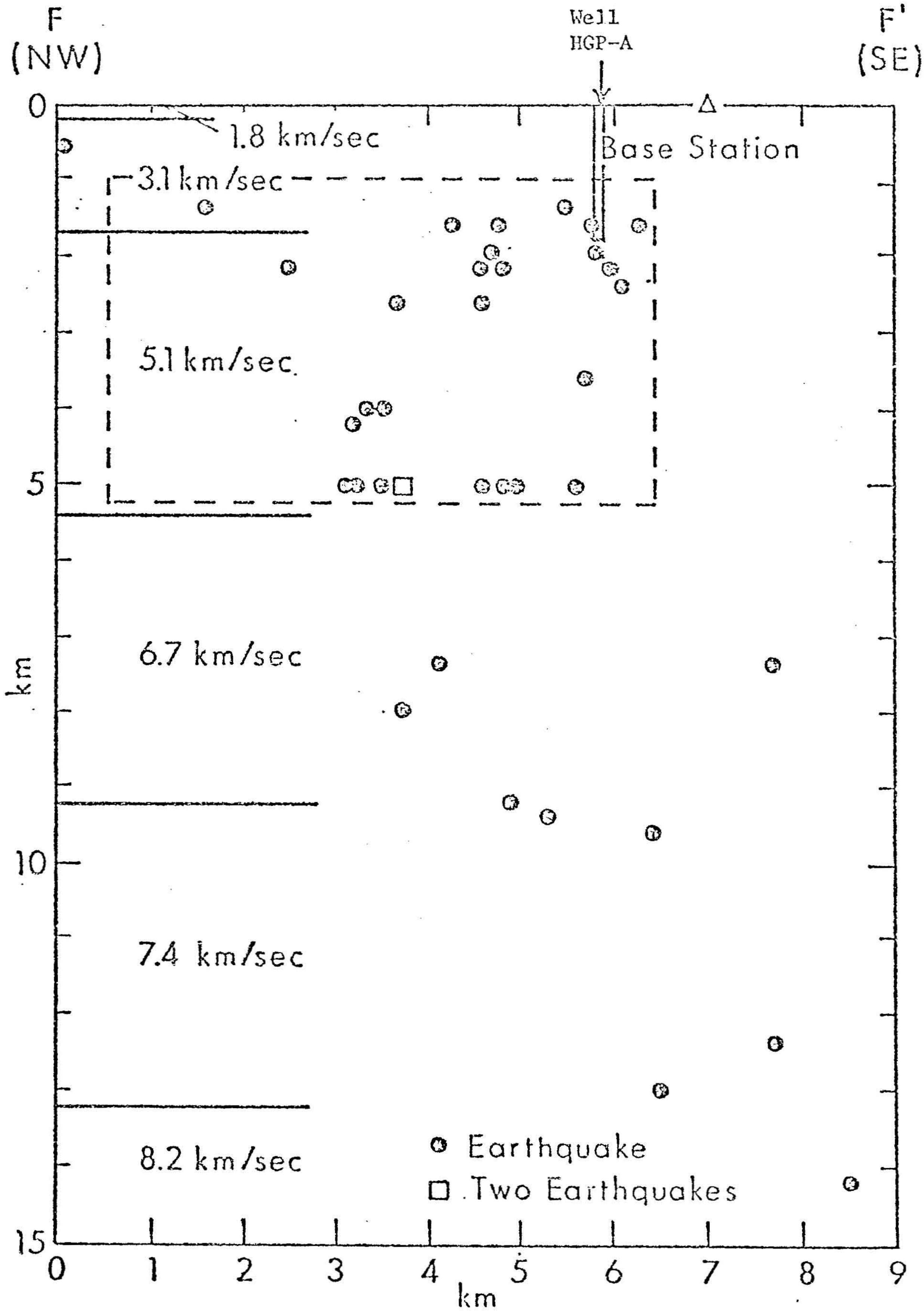


Figure 6. Foci of earthquakes projected on plane AA' in Fig. 5. Broken line shows dike complex by gravity data.

extent of the reservoir although their sharp commencement at reservoir depth suggests that this technique can be used for this purpose.

We, therefore, propose to acquire another longer data set in an attempt to define more adequately the volume over which these microearthquakes are present. During Phase III of HGP, we determined a seismic velocity structure for the vicinity of the reservoir. This new velocity structure combined with additional field observations (made with an array centered on the current well site) should greatly increase the accuracy with which these events can be located. Once we have a large number of accurately-located events, we can identify a volume that is representative of the reservoir volume.

A second technique for analyzing seismic signals was also used during the exploration phases of HGP; namely, the nature of the seismic ground noise of the region. This work identified a seismic "noise high" of about 9 db in the immediate region of the well. Unfortunately, the areal extent of this "noise high" is broad and its boundaries are diffuse.

It is unlikely that conventional ground noise studies; i.e., noise amplitude vs. position, can be much better than we have already done. However, noise coherence studies may be more successful. These studies use both the amplitude and phase of the noise signal to assist in location of the noise source. During the past year, we have developed the necessary computer software to perform this type of analysis. We now need a data set to use in the analysis.

2. Proposed Field Program

We propose to deploy 5 digital seismic stations each capable of recording 3 seismic channels in an optimized array essentially centered on HGP-A. These stations will be used to record both microearthquakes and ground noise. All the necessary equipment for this work currently exists in the Hawaii Institute of Geophysics, and all the computer software for optimization of the array and analysis of the data currently exist (or are being developed in other programs).

Figure 7 indicates the proposed deployment of these instruments as well as the assumed dimensions of the reservoir based on our earlier data. Each of the 5 instruments will be deployed as 3 vertical sensors separated by up to a kilometer from each other. Thus, the total array will consist of 5 subarrays of 3 elements each. This distribution of sensors will enable us to do local directivity studies as well as a composite solution for the total array. Each of the instruments will record in a broad-band, digital, event-detecting mode

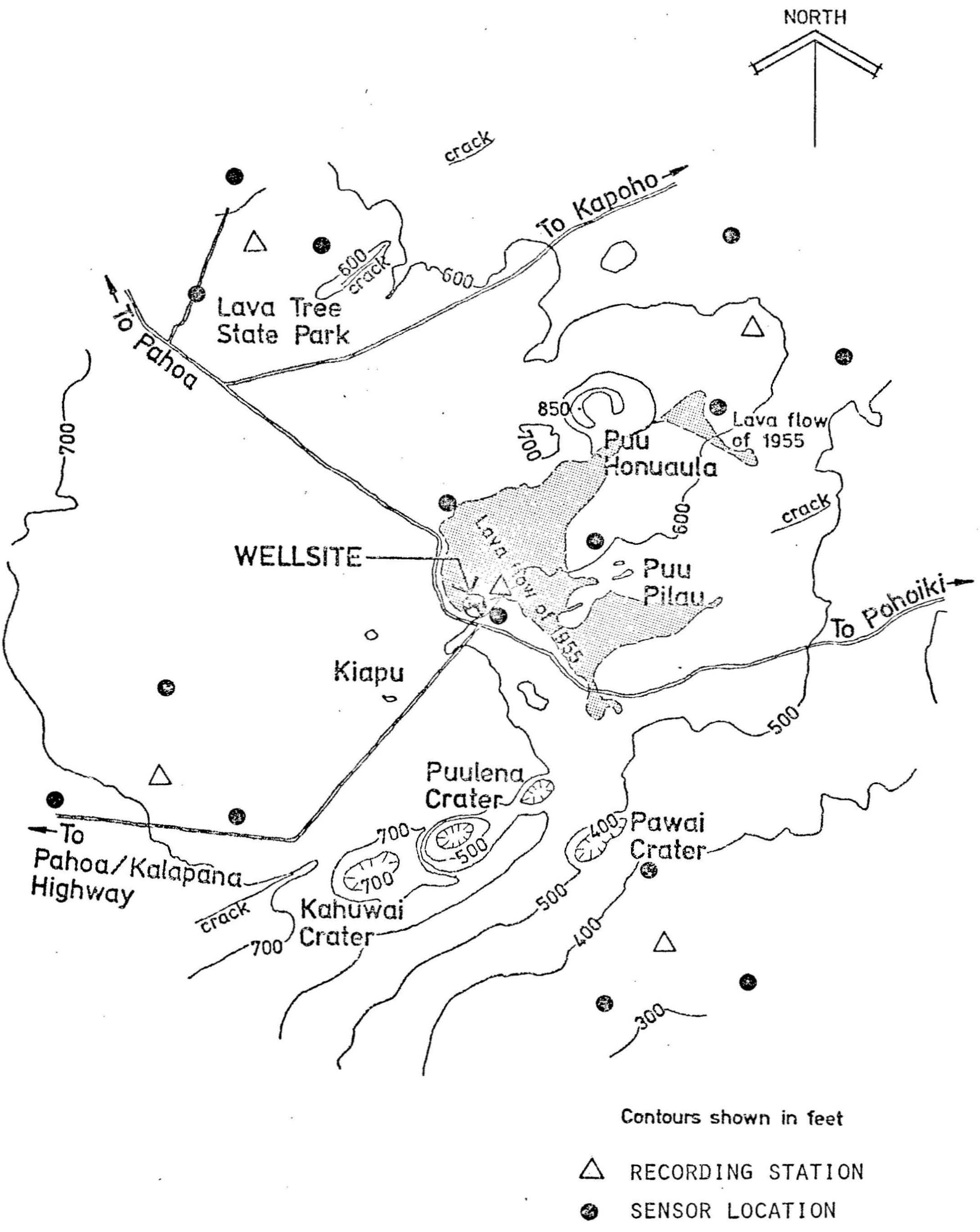


FIGURE 7. SITE LOCATION

for the period of 10 pm to 4 am and then automatically convert to a continuous recording mode for the next 2 hours. Cultural noise (cars, tractors, etc.) is so great during the day that no effort will be made to record during this period. The instruments are capable of recording up to 200 events, or 3 hours of continuous recording or a combination of both, and will run for about 30 days on one set of batteries, requiring only a daily change of tape cassettes and time calibration.

Analysis of the data will include identification of and location of all local earthquakes (within 10 km of the array) using standard microearthquake techniques. In addition, several subsets of the noise recorded prior to and during earthquakes, continously recorded, will be analyzed for noise coherence and directivity both across the subarrays and across the total array. The resulting distribution of microearthquakes combined with the subarray and total array noise-coherence studies should permit a refinement in the definition of boundaries of the region of microearthquake activity and correlation of these boundaries with the boundaries derived from the noise coherence studies.

D. Reservoir Engineering

The long-term objective of the reservoir engineering effort is a comprehensive assessment of the Kapoho geothermal reservoir associated with HGP-A, leading to estimates of areal extent, depths and thicknesses of producing layers, and production life. While a step-out well(s) is an essential component of such a program, it is possible to obtain preliminary indications of the approximate locations and permeabilities of producing layers by utilizing a series of carefully-planned tests which can be conducted with HGP-A alone. These tests include (1) pumpdown tests, (2) slow (non-flashing) tests, and (3) dye-tracer tests. In addition, a method to handle the silica in the fluid will be investigated.

1. Pumpdown Tests

The temperature profile in the wellbore of HGP-A after it has been shut in for a period of time is shown in Figure 2. In the upper region of the portion that is cased, from surface to 1500 feet, the temperature is roughly 75°C, followed by a sharp gradient to a temperature of 200°C at 2500 feet, and eventually to 280°C at 4000 feet to 6000 feet. The temperature increases again at bottomhole.

If cold water is forced into the wellbore from the surface, there will be a fairly small zone where the newly-introduced water will mix with the fluid originally in the wellbore. In general, however, the hotter fluid will be forced deeper into the wellbore ahead of the cold water. As pressure is increased due to pumping and the introduction of cold water at the surface, wellbore fluid will be forced back into the formation, into that layer which is the most permeable. The hotter wellbore fluid that is between the permeable layer and the advancing cold water front will then be forced into the formation with the result that there will be cold water above the permeable layer with hotter wellbore fluid below the permeable layer. Detection of this abrupt temperature change will yield the location of the permeable layer. As pumping pressure is increased, fluid is forced into the formation at the next most permeable layer with the attendant sharp temperature change at that depth.

To locate these permeable layers, a pumpdown test procedure has been formulated. Following a period of quiescence after the wellbore has reached thermal equilibrium (as ascertained by a series of temperature profiles), cold water will be pumped down under pressure into the wellbore. The back pressure and flow rate during pumpdown will be recorded. Immediately after pumping is stopped, a series of temperature profiles will be taken. These profiles will be examined for any sharp changes in temperature which would indicate the presence of permeable layers. The relative permeabilities of these layers would be given by the back pressure required to maintain the pumpdown flow rate.

2. Slow Flow Tests

In a well which has several producing layers, it is possible to gain an indication of the locations of these producing layers by measuring the flow rates at various depths in the wellbore. Using a flow meter (spinner) to measure flow rates at various depths, a graph of flow rate vs. depth can be constructed. In regions with little or no production, there should be little change, if any, in the flow rate with depth. Producing layers, however, will be accompanied by large changes in flow rate with depth.

Subsurface flow meters in current production, e.g., by Kuster, are volumetric flow rate sensing devices with output in, say, barrels per hour. Hence, in order to obtain a mass flow rate, the density of the fluid must be known. This precludes the use of these types of flow meters for measuring the two-phase flow in HGP-A.

To avoid this difficulty, a slow (non-flashing) flow test using a Kuster flow meter will be conducted. In this test the wellhead conditions will be adjusted so that the fluid in the wellbore will be completely in the liquid state. A flow meter will be used to measure the flow rates at the surface and at a known depth to determine the fraction of the total flow originating from below that depth. From a series of these tests with the flow meter located at predetermined depths, the approximate locations and thicknesses of the producing layers can be inferred.

The presence of the slotted liner in the wellbore of HGP-A will present some problems in the interpretation of the slow flow test results. While the flow meter will be measuring the flow rate through the central core of the slotted liner, there will be some bypass through the outer, annular region between the slotted liner and the rockface. However, the dimensions of the slotted liner (6.969 inch I.D., 7.625 inch O.D.) and the drilled hole (8 1/2 inch diameter) yield equivalent hydraulic diameters (4 x cross-sectional area of flow/perimeter) of 6.969 inch for the cylindrical core in the slotted liner and 0.875 inch for the annular region outside the slotted. With these values and the measured flow rate in the cylindrical core, it is possible to estimate the fraction of the total flow that is being bypassed in the annular region.

3. Dye-Tracer Tests

During the well's quiescent period, it is suspected that fluid is continuing to flow in the well from the lower, hotter producing layer or layers to a higher permeable layer near the bottom of the casing. This higher layer normally produces "cold" fluid, probably ocean water as discussed previously, during well production; however, during the well's initial flashing period, it first produces the hotter fluid which has flowed into it from the lower but hotter producing layers and then produces the colder fluid.

To detect the movement of the fluid during quiescent periods a technique used in water well studies will be used. A special dye is released at specific depths and the movement of the dye traced by sampling the fluid in the wellbore at various depths. Tracing the dye movement will produce information on the influx and outflow layers.

4. Disposal System for HGP-A Well Effluent

The system to be tested consists of two principal components: (1) a silica precipitation basin, and (2) a land disposal basin. The silica in the effluent entering the disposal system will precipitate from the solution as the solution is cooled. The idea is to remove part of it in a low-cost precipitation basin which is expendable and to allow the remainder to go with the liquid to the land disposal basin where infiltration and percolation will take place. Silica incrustating and scarifying of the disposal basin surface are expected. The system life is uncertain because there are practicably no design data available.

The system design will permit considerable operational flexibility by the operator. For operation and future design, data will be recorded on the hydraulic loading, apparent rate of liquid intake in the disposal basin, apparent rate of incrustation in both precipitation and disposal basin, liquid temperature at the inlet and outlet of precipitation basin, and in the disposal basin.

The precipitation basin will be made of wood with a floor and walls. Baffle walls will also be added to increase detention time and silica precipitation. The land disposal basin will be below grade, unlined, and covered with loose material that can be scarified.

E. Impact of HGP-A Effluent on the Environment

Hydrothermal fluids from HGP-A can enter the environment, both in gaseous and liquid forms. Potential toxicants carried in these respective fluid modes require different treatment and handling. The geotoxicological assessment of the introduction into the atmosphere of possible pollutants initially will be an extension of the existing information on the reservoir in close proximity to HGP-A. Assuming that reservoir geochemistry proximal to HGP-A is uniform, the intensive monitoring of air mercury levels carried out in previous studies will be replaced by periodic checks, and efforts will be focused upon H_2S and derivative sulfur oxides. This program will extend over the populated areas including Pahoa, Naniwale, Leilani Estates, etc. Discharge waters from HGP-A will be re-examined for a range of toxic elements including mercury, arsenic, thallium, cadmium, etc. One new feature will be soil and air sampling for acidity as a sign of sulfuric acid aerosols generated by H_2S oxidation.

The current program of "mapping" natural sources of toxic gases including mercury, H_2S and sulfur oxides will be extended from Hawaii Volcano National Park sites to locations southward and eastward into the Puna district. These data will provide a more reliable basis for evaluating and distinguishing natural and anthropogenic (geothermal) contributions to "pollution".

In addition to continuing chemical analysis of liquids for non-volatile toxic elements, including arsenic and thallium, both known in the Hawaiian environment, bioassay of these waters will be carried out by growing plants in chemically inert substrates and comparing known "clean" water with discharge fluids from the well. Plants, well-known in physiological, nutritional and pollution research such as bean and cucumber, will be used. The bioconcentrative capabilities of these plants is an advantage in the analysis of plant tissues for toxic metals. Indicator plants will also be arrayed around the general HGP-A area as an adjunct to chemical methods for sulfur-oxide emission.

F. Project Integration and Support

Because a number of researchers will be involved in the various parts of Phase IV, some coordination will be necessary so that the principal investigator will be able to manage the program effectively. To insure that the resultant data analyses are integrated into a complete, unified synthesis of the Kapoho geothermal reservoir, an Executive Committee consisting of key people in the Project and chaired by the principal investigator will meet regularly to discuss efforts, results and problems. Administrative, stenographic and fiscal support will be provided to the researchers on the Project by the present staff.

The personnel of the HGP will also provide assistance to the HGP-A Development Group and aid in the installation of a wellhead generator at HGP-A. Liaison will be maintained by the principal investigator. In addition, since the efforts of the HGP have been primarily responsible for the present active interest in the further development of geothermal energy in the State of Hawaii, we will continue to assist this development wherever possible. Active leasing of lands on the Big Island and Oahu is already underway although only HGP-A has been drilled. The proving of the Kapoho geothermal reservoir will go a long way to encourage the future development of geothermal energy in Hawaii. Representatives of the manganese nodule consortia have visited Hawaii and are seriously considering the Big Island as the location for one of the first manganese nodule processing plants. Energy needs would be supplied by electricity generated by geothermal energy. However, more data must be made available on the field if the Kapoho reservoir is to remain a viable candidate for supplying the energy.

The 1978 annual meeting of the Geothermal Resources Council will be held in Hilo, Hawaii with technical papers to be presented on July 25-27, 1978 and tours of HGP-A and the Kilauea Volcano area scheduled for July 28. The principal investigator is a co-chairman of the meeting, and personnel from HGP are assisting with local arrangements, field trips, and general planning. HGP researchers will be presenting at least five technical papers at the meeting.

III. BUDGET

The budget for the proposed research, which is the first part of Phase IV of the Hawaii Geothermal Project, is given on the following pages. Vitae for Project personnel follow the budget. Personnel whose vitae are included but for whom no support is requested will be supported by other sources.

BUDGET

1.	Salaries and Wages		$ 34,846
	Scientific discipline personnel		
	Principal Investigator, P. Yuen, Acting Dean of Engineering, 75% of time for 1 summer month @ $3419 per month	2,564	
	Faculty Associate - senior personnel, C. Helsley, Director of Hawaii Institute of Geophysics, 100% of time for 1 summer month @ $3466 per month	3,466	
	Faculty Associate, D. Kihara, Associate Professor, 100% of time for 1 summer month @ $2564 per month	2,564	
	Research Associate, J. Gettrust, 100% of time for 1 month @ $1585 per month	1,585	
	Research Associate, A. Seki, 75% of time for 3 months @ $1174 per month	2,642	
	Research Associate, D. Thomas, 50% of time for 5 months @ $1389 per month	3,473	
	Research Associate, 100% of time for 1 month @ $1422 per month	1,422	
	Graduate Student, 50% of time for 5 months	2,455	
	Graduate Student, 50% of time for 4 months	1,964	
	Support personnel		
	Electronic Technician, 100% of time for 1 month @ $1542 per month	1,542	
	Administrative Officer, D. Sakai, 75% of time for 3 months @ $907 per month, 3 months @ $957 per month	4,194	
	5 Pre-baccalaureate Students.	6,975	
2.	Fringe Benefits		4,378
3.	Permanent Equipment		16,300
	a. Downhole water sampling bottle	4,500	
	b. Kuster subsurface instruments	11,800	
	Recorders (2) $2,000		
	Clocks (4) 2,000		
	Pressure elements (2) 800		

Flow meter 6,000		
Temperature elements (2) 1,000		
4. Travel		12,740
Interisland travel	12,240	
1 trip to Mainland	500	
5. Other Direct Costs		14,940
Expendable equipment and supplies (includes winch wire, replacement parts for equipment)	4,700	
Publications and graphics	1,340	
Water chemistry and isotope analyses charges	4,500	
Computer services	2,000	
Other: communications, xeroxing, shipping, playback charges, etc.	2,400	
6. Indirect Charges: 48.2% of Salaries and Wages		16,796
TOTAL PROJECT COSTS		$100,000

Excluded Curriculum Vitaes

p. 32 to 68 contained curriculum vitaes of the following people:

Paul Yuen
Bill Chen
Joseph Gettrust
Charles Helsley
Deane Kihara
Peter Kroopnick
L. Stephen Lau,
Arthur Seki
Barbara Siegel
Sanford Siegel
Patrick Takahashi
Donald Thomas

These CVs were excluded from this digitized document for privacy reasons.